
26 Model-Free Adaptive Control Software

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INTRODUCTION

A modern plant-wide automation and information technology system should comprise the following subsystems or layers: regular regulatory control (RRC), advanced regulatory control (ARC), advanced process control (APC) and optimization, statistical quality/process control (SQC/SPC), scheduling, and enterprise resource planning (ERP). These subsystems can be automated by using instrumentation and computers with appropriate software. The relationship between them can be illustrated in the pyramid graph in [Figure 26.1](#). Each layer relies on the underlying layer(s) to be effective. For instance, an APC and optimization system relies on good regulatory control of the process.

The RRC layer can be referred to as the basic automation layer, where sensors, actuators, and controllers form feedback control loops for process variables such as flow, pressure, level, temperature, etc. Single- or multi-loop controllers, programmable logic controllers (PLCs), programmable automation controllers (PACs), and distributed control systems (DCS) are the typical control instruments used in this layer. The proportional-integral-derivative (PID) controller is the workhorse in these control instruments. Although PID algorithms may have different types and formulas, they are basically the same as those being used since the early 1940s, when the automation industry started. PID controllers are simple, easy to understand, and can control most processes.

The ARC layer, as the name suggests, applies advanced control methods to the processes that are more complex and difficult to control. Since these processes may be nonlinear, time-variant, multivariable, or have large time delays and major disturbances, the traditional PID control methods would not be effective. Although there are multiple control methods that can be used in the ARC layer, they can be characterized as (i) model-free adaptive (MFA) control and (ii) model-based control (MBC) methods. In this section, we will mainly discuss the MFA control methods and related software products.

The APC and optimization layer is mainly for optimizing the throughput for a large operating unit. Model predictive control (MPC) is the most popular APC and optimization method. MPC is based on three key elements: (i) predictive model, (ii) optimization in the range of a temporal window,

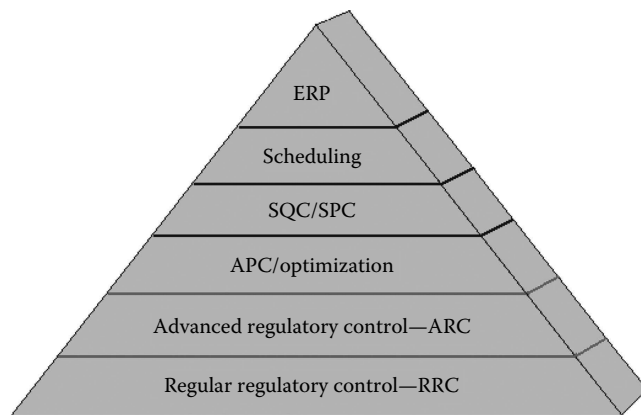
and (iii) feedback correction. MPC is based on the predictive model of the process, which is used to predict the future output based on the historical information of the process as well as future input. MPC is an optimal control algorithm. It calculates future control action based on a performance function. The optimization of MPC is limited to a moving time interval and is carried on continuously. The moving time interval is called a temporal window. This is the key difference compared to traditional optimal control that uses a performance function to judge global optimization. MPC is also a feedback control algorithm. If there is a mismatch between the model and process, or if there is a control performance problem caused by the system uncertainties, MPC could compensate for the error or adjust the model parameters based on online identification. When an APC and optimization system is implemented and used properly, a large payback could be realized.

The SQC/SPC subsystem monitors and controls the product quality using statistical methods. The scheduling subsystem sets the production schedule for what to produce, how many to produce, and when. The ERP subsystem manages internal and external resources including tangible assets, materials, and financial and human resources.

The question then is how to select the appropriate control methods for the required applications? Here is a rule of thumb guideline. If a process is relatively simple, RRC will be sufficient. If a process is complex with nonlinear, multivariable, large time delays, or frequent dynamic changes, ARC is required. After a solid closed-loop regulatory control system is implemented using RRC and ARC, an APC and optimization system can then be designed for maximizing the production throughput under process and equipment constraints. Without a good regulatory control foundation, APC can be costly and not effective. [Table 26.1](#) is a comparison summary of RRC, ARC, and APC.

MODEL-FREE ADAPTIVE CONTROL

Developed by CyboSoft, General Cybernation Group Inc., Model-free adaptive (MFA) control, as its name suggests, is an adaptive control method that does not require process models. Based on the “intelligent” nature of artificial neural networks (ANNs), MFA can adapt to new operating conditions

**FIG. 26.1**

Pyramid of a modern plant-wide automation and IT system.

and control complex systems without requiring process models. MFA can control tough processes including nonlinear, open-loop oscillating, and multivariable processes. MFA controllers can also handle processes with large time delays, varying dynamics, and changing operating conditions. Once installed, no controller manual tuning is required.

Definition of MFA Control

A Model-Free Adaptive (MFA) control system is defined to have the following properties:

- No precise quantitative knowledge of the process is available.
- No process identification mechanism or identifier is included in the system.
- No controller design for a specific process is needed.
- No manual tuning of controller parameters is required.

- Closed-loop system stability analysis and criteria are available to guarantee the system stability.

Please note that there may be publications discussing control methods using similar names such as MFAC [29]; they do not have the same definition, property, architecture, algorithms, and techniques as the MFA control method presented in this chapter. Due to the length limitation, detailed discussions about these five key points are not presented here but can be found in Refs. [1–11].

Based on the core MFA technology, a series of MFA controllers have been developed to address specific control problems:

- SISO MFA to replace PID and control simple to complex processes
- MIMO MFA to control multivariable processes
- Anti-delay MFA to control processes with large time delays
- Robust MFA to force the process variable to stay within defined bounds
- Feedforward MFA to deal with measurable disturbances
- Nonlinear MFA to control nonlinear processes
- MFA pH controller to control pH processes
- Anti-delay MFA pH controller to control pH processes with large time delays
- Feedforward MFA pH controller for pH processes with large inflow changes
- Time-varying MFA to control time-varying processes
- Flex-phase MFA to control open-loop oscillating processes
- MFA optimizer to dynamically search for the min or max condition
- MFA XRT controller to control exothermal reactor temperature (a run-away process)

TABLE 26.1

Comparison of Control and Optimization Layers

<i>Item</i>	<i>RRC</i>	<i>ARC</i>	<i>APC/Optimization</i>
Control algorithm	PID	MFA	MPC, DMC
Where to implement	DCS, PLC	DCS, PLC, computer	DCS, computer
Main control objectives	Regulating and tracking	Regulating and tracking	Generate optimal setpoints
Variable	Single	Single or multivariable	Single or multivariable
Need process model	No	No	Yes
Need controller design	No	No	Yes
Need identification	No	No	Yes
Need controller manual tuning	Yes	No	Yes/no
Control complex systems	No	Yes	Yes
Investment	Fair	Fair	Large
Expertise level required	Medium	Medium	High
Commissioning	Easy	Easy	Difficult
Maintenance	By Case	Easy	Difficult
ROI	Fair	High	Can be high

For example, pH control is needed in just about every process plant, and yet a large percentage of pH loops perform poorly. This results in inferior product quality, environmental pollution, and material waste. The MFA pH controllers are applicable in controlling pH loops for industrial wastewater treatment processes, especially for those pH loops that have large time delays and varying inflows.

MFA Control Approach

The MFA control approach overcomes the major weaknesses of PID and MBC in the following ways:

1. PID is basically a “one-algorithm-fits-all” method. Inevitably, its capability is limited. In other words, PID is more like a general-purpose medicine. Except, there is no way for one medicine to effectively cure all illnesses.
2. Model-based control (MBC) is more like a “one-algorithm-fits-one-system” method. If the process dynamics do not change frequently and the process model can be well maintained, MBC can provide good performance. However, since it is so specialized and has a potentially high installation and maintenance cost, large deployment may be difficult.
3. MFA control takes a “one-algorithm-solves-one-problem” approach. Each MFA controller is designed to solve a difficult control problem while neither process model nor identification is required. For instance, the Nonlinear MFA controller can control various types of extremely nonlinear processes in different industries and applications. Each MFA controller is like a specifically developed medicine to cure one specific ailment. Therefore, large deployment is possible.

This design philosophy is based on the Combined Intelligence MFA Methodology that is presented in the last part of this chapter. We will also present several application case studies to show solutions to difficult control problems using MFA.

MFA Advantages and Suitability

Every technology and method have their advantages and suitability. So do PID, MBC, and MFA. Figure 26.2 illustrates

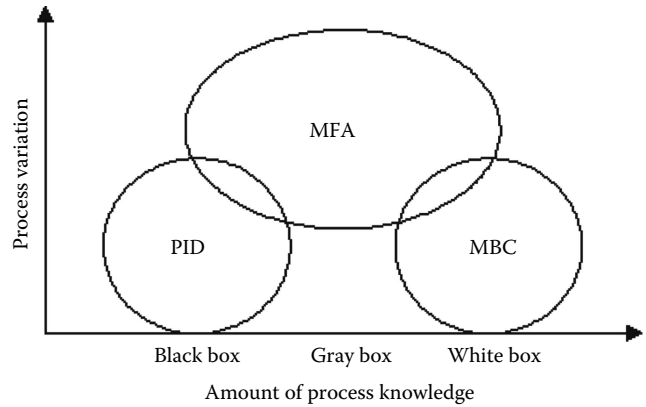


FIG. 26.2
Suitability of different control methods.

the suitability of PID, MFA, and MBC. PID is a controller for a large variety of processes where no detailed process information is required (Black Box). However, since PID is a fixed controller, it cannot deal with process dynamic changes. The MBC is well suited for controlling a process where detailed knowledge is available (White Box). For instance, when an airplane is designed, its mathematical models can be obtained. So, a perfect control system can be designed using model-based methods to control the airplane. MFA is suitable for controlling processes with qualitative process knowledge but no detailed process models are available (Gray Box). In addition, the process dynamics can have significant variations. Many industrial processes are gray boxes that have frequent load, fuel, and dynamic changes.

SINGLE-LOOP MFA CONTROL SYSTEMS

Figure 26.3 illustrates a single-loop MFA control system that includes a single-input-single-output (SISO) process, a SISO MFA controller, and a feedback loop. The control objective is for the controller to produce an output $u(t)$ to force the process variable $y(t)$ to track the given trajectory of its setpoint $r(t)$ under variations of setpoint, disturbance, and process dynamics. In other words, the task of the MFA controller is to minimize the error $e(t)$ in an online fashion, where $e(t)$ is the difference between the setpoint $r(t)$ and

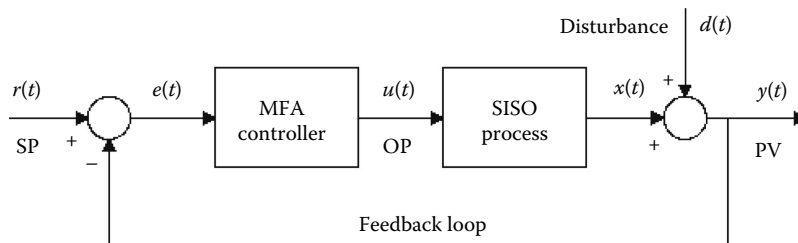


FIG. 26.3
Single-loop MFA control system.

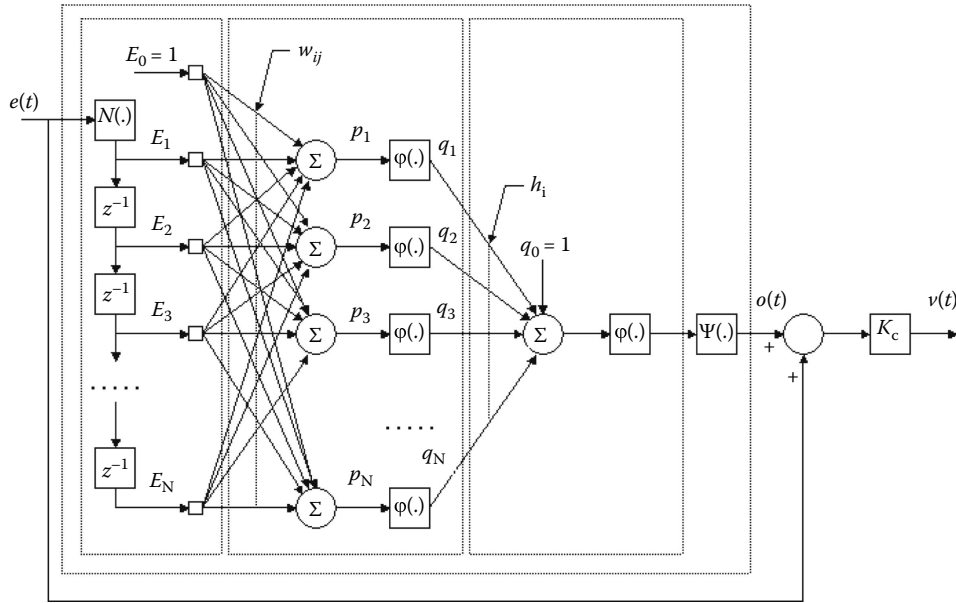


FIG. 26.4
Architecture of a SISO MFA controller.

the process variable $y(t)$. The minimization of error $e(t)$ is achieved by (i) the regulatory control capability of the MFA controller and (ii) the adjustment of the controller-weighting factors that allow the MFA controller to deal with process dynamic changes, disturbances, and other uncertainties. In this document, we may also use SP for setpoint, PV for process variable, and OP for controller output.

Controller Architecture

The architecture of a SISO MFA controller is illustrated in Figure 26.4, where an ANN is used as a key component. It is important to know that the neural network (NN) in MFA is not used as a model, but rather as a dynamic block that is part of the controller.

The NN has one input layer, one hidden layer with N neurons, and one output layer with one neuron. Within the NN, there is a group of weighting factors (w_{ij} and h_i), which can be updated as needed to vary the behavior of the controller. The algorithm for updating the weighting factors is based on the goal of minimizing the error between the setpoint and process variable. Since this effort is the same as the control objective, the adaptation of the weighting factors can assist the controller in minimizing the error while process dynamics are changing. The ANN-based MFA controller saves and uses a portion of the process data, which also provide information for the process dynamics. In comparison, a digital version of the PID controller saves only the current and previous two samples. In this regard, PID has almost no memory and MFA possesses the memory that may be useful to a “smart” controller [1,11,12].

SISO Control Algorithm

The key portion of the MFA control algorithm includes the following difference equations:

$$p_j(n) = \sum_{i=1}^N w_{ij}(n) E_i(n) + 1, \quad (26.1)$$

$$q_j(n) = \varphi(p_j(n)), \quad (26.2)$$

$$o(n) = \Psi \left[\varphi \left(\sum_{j=1}^N h_j(n) q_j(n) + 1 \right) \right] = \sum_{j=1}^N h_j(n) q_j(n) + 1, \quad (26.3)$$

$$v(t) = K_c [o(t) + e(t)], \quad (26.4)$$

where

n denotes the n th iteration

$o(t)$ is the continuous function of $o(n)$

$v(t)$ is the output of the controller

$K_c > 0$ is the MFA controller gain that is useful for adjusting the control performance

The weighting factors are updated online at every sample interval using the following formulas:

$$\Delta w_{ij}(n) = \eta K_c e(n) q_j(n) (1 - q_j(n)) E_i(n) \sum_{k=1}^N h_k(n), \quad (26.5)$$

$$\Delta h_j(n) = \eta K_c e(n) q_j(n). \quad (26.6)$$

More detailed MFA control algorithms and discussions can be found in Refs. [1–3].

Adaptive Capability of MFA Control

As illustrated in Figure 26.5, the adaptive capability of MFA (top) is shown when compared with PID (bottom), where MFA adapts when process dynamics change. From the beginning, MFA (top) and PID (bottom) are controlling two identical processes with similar control performance. Then, both processes have a major dynamic change causing the systems to oscillate. The PID system will continue to oscillate while MFA quickly adapts to show better control. When the setpoints are changed again, the MFA system no longer shows oscillation since it has adapted to the new condition.

MFA Control System Requirements

Most automatic controllers including MFA and PID require that the processes should be *controllable*, *open-loop stable*, and either *direct* or *reverse acting*, that is, the process does not change signs.

1. A process is controllable when the control output used as the process input is capable of moving the process output to any position within its predefined range in a finite time. This applies to the SISO process and the main loops of the multi-input–multi-output (MIMO) process. If the process is not controllable, improvement of the process design or variable pairing is necessary.

2. A process is open-loop stable if for any bounded process input, the process output is also bounded. This is called bounded-input–bounded-output (BIBO) stable. This applies to the SISO process and all the subprocesses of a MIMO process. If the process is not open-loop stable, it should be stabilized before applying a standard MFA controller. However, for certain simple open-loop unstable processes such as a non self-regulating level loop, no special treatment is required when using MFA.
3. If a process changes its sign within its operating range, a regular controller will fail since the negative feedback loop may change to a positive feedback loop, causing the control system to be unstable. In this case, the process input and output may have a parabolic relationship with a maximum or minimum point. The MFA Optimizer can be used to search for that optimal operating point. The fuel–air ratio of a combustion process is a good example of such a process, where the maximum combustion efficiency exists.

MULTIVARIABLE MFA CONTROL SYSTEMS

In control applications, most processes have multiple inputs and multiple outputs with interactions in between. The level and density loops of an evaporator and the temperature loops of a multi-zoned furnace are good examples of such a multivariable process. In many cases, lacking general-purpose multivariable controllers, a large percentage of multivariable processes are treated as single variable processes resulting in poor control, wasted energy and materials, inconsistent quality, and plant upsets.

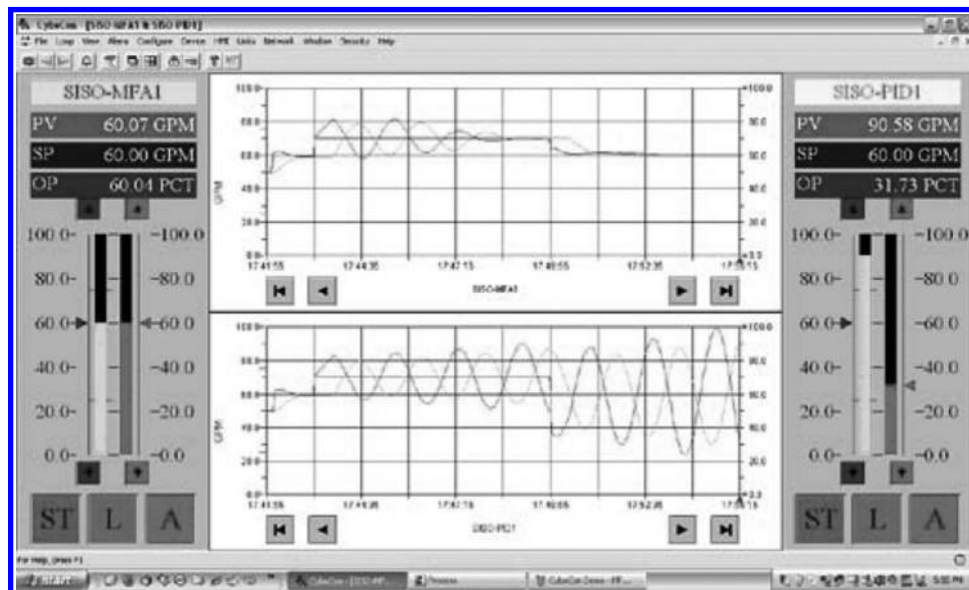


FIG. 26.5
Comparison of MFA and PID.

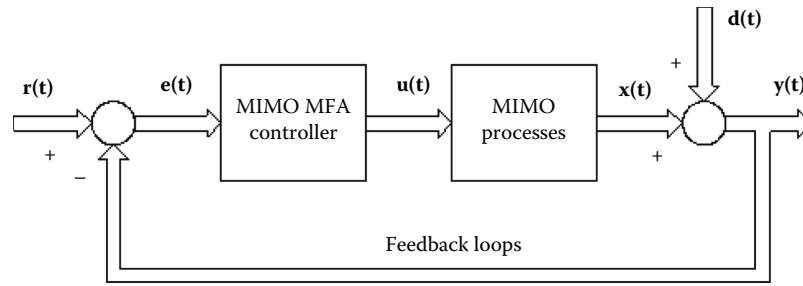


FIG. 26.6
Multivariable MFA control system.

Figure 26.6 illustrates a multivariable MFA control system, which consists of a MIMO process, a MIMO MFA controller, and multiple feedback loops.

Similar to a SISO system, the MIMO system has controller setpoints $\mathbf{r}(t)$, error signals $\mathbf{e}(t)$, controller outputs $\mathbf{u}(t)$, process variables $\mathbf{y}(t)$, and disturbance signals $\mathbf{d}(t)$. Since it is a multivariable system, all the signals here are vectors represented in bold case.

2-Input–2-Output MFA Control System

Without losing generality, we will show how a MIMO MFA controller works with a 2-input–2-output (2×2) MFA control system as illustrated in Figure 26.7. In the 2×2 control system, the 2×2 MFA controller consists of two main controllers C_{11} , C_{22} , and two compensators C_{21} , and C_{12} . The process has four subprocesses G_{11} , G_{21} , G_{12} , and G_{22} .

The feedback signals for the main control loops are the measured process variables y_1 and y_2 , which are compared with the setpoints r_1 and r_2 to produce errors e_1 and e_2 . In this case, there are two feedback loops. The output of each subprocess x_{11} , x_{21} , x_{12} , and x_{22} is cross-added to produce

measured process variables y_1 and y_2 . Thus, by the nature of the 2×2 process, the inputs u_1 and u_2 to the process are interconnected with outputs y_1 and y_2 . The change in one input will cause both outputs to change.

The control objective for the 2×2 MFA control system is to produce control outputs $u_1(t)$ and $u_2(t)$ to force the process variables $y_1(t)$ and $y_2(t)$ to track their setpoints $r_1(t)$ and $r_2(t)$, respectively. The minimization of $e_1(t)$ and $e_2(t)$ is achieved by (i) the regulatory control capability of the MFA controllers, (ii) the decoupling capability of the compensators, and (iii) the adjustment of the MFA weighting factors that allow the controllers to deal with the process dynamic changes, large disturbances, and other uncertainties. Detailed MIMO MFA control algorithms as well as other MFA control algorithms are quite complex and omitted here. Interested readers can find more information in Refs. [2–12].

Notice that in real applications, the outputs from the subprocesses are not measurable and only their combined signals y_1 and y_2 can be measured. Therefore, it is difficult to find the subprocess models G_{11} , G_{21} , G_{12} , and G_{22} using a MBC approach. On the other hand, a 2×2 process has four subprocesses, and a 3×3 process has nine subprocesses,

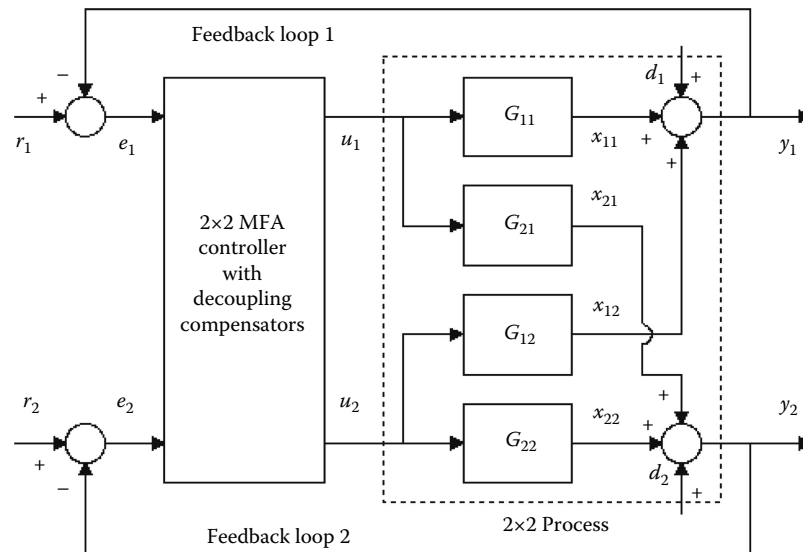


FIG. 26.7
A 2-Input–2-Output MFA control system.

TABLE 26.2*MFA Control Software and Controllers*

<i>Software Name</i>	<i>Controller</i>
CyboCon MFA Control Software	SISO MFA controller
	Nonlinear MFA controller
	MFA pH controller
	Time-varying MFA controller
	Anti-delay MFA pH controller
	MFA XRT controller
MFA Control Toolset for LabVIEW software	Feedforward MFA controller
	Anti-delay MFA feedforward controller
	Robust MFA controller
	3×3 MIMO MFA controller
MFA Control Toolbox for MATLAB software	SISO MFA controller
	2×2 MIMO MFA controller

and an $n \times n$ process will have up to n^2 subprocesses. Just by knowing the number of subprocesses in a large-scale multi-variable process, it is not hard to imagine the complexity of the work required when using MBC methods.

MFA Control Software Products

In the following sections, we will discuss three types of MFA control software. Table 26.2 lists the MFA controllers to be described in each of the software products.

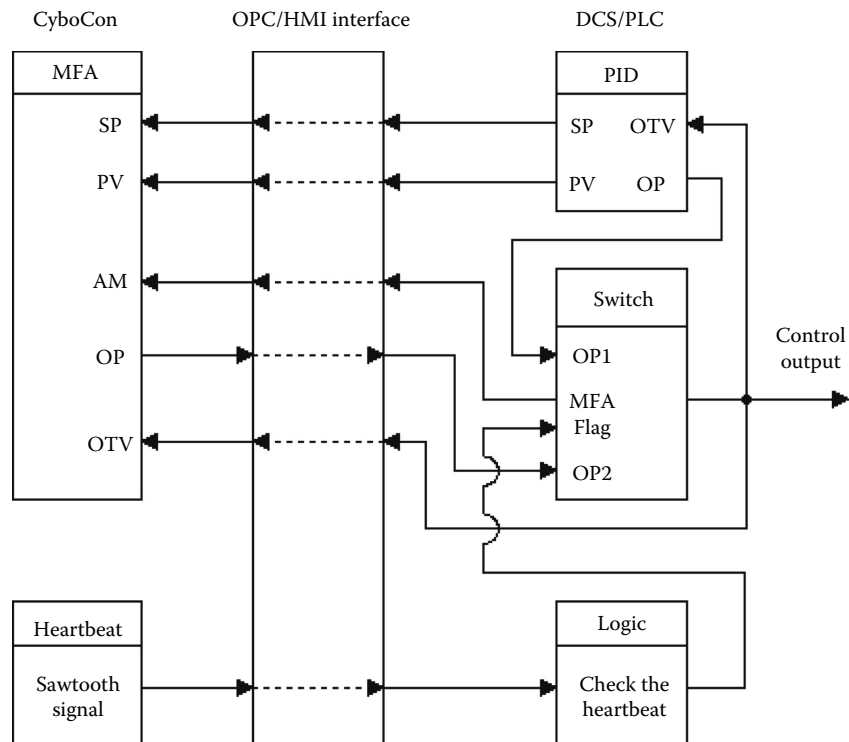
CyboCon MFA Control Software

CyboCon is CyboSoft's flagship MFA control software product, which includes all standard SISO and MIMO MFA controllers. The Professional Editions of CyboCon software may include special MFA controllers and function blocks suitable for a specific application.

Running in Windows PC, the MFA controllers can interface to DCS and PLC through OPC, HMI software, interface drivers, or direct I/O wiring. As illustrated in Figure 26.8, the signals of a control loop including setpoint (SP), process variable (PV) and controller output (OP), output tracking variable (OTV), and auto manual (AM) are connected between an MFA controller in CyboCon and a PID controller in DCS/PLC. When MFA or PID is in manual mode, its OP will track its OTV signal.

A heartbeat signal can be configured in CyboCon software and be sent to the DCS/PLC to confirm that the communication between the PC and DCS/PLC is working. In case the DCS/PLC detects the loss of the heartbeat signal, it will switch to DCS/PLC control or manual control. Since MFA and PID are tracking the current control output when it is in manual mode through its OTV, the switching between MFA and PID can be done at any time and is bumpless.

A CyboCon-based industrial PC can be considered an ARC station. Many MFA control systems are implemented in this way and the safety feature makes the system reliable.

**FIG. 26.8***CyboCon and DCS/PLC interface diagram.*

SISO Control Block - Modify

General
 Tag: SISO-MFA1 Unit: GPM ID: 1
 Controller Type: MFA Turbo Time Constant: 20
 Sample Interval: 0.5 ☐ Reverse Acting ☐ Auto On Start

Limits

	Lower	Upper
PV	0	100
SP	0	100
OP	0	100
PV (Alarm)	25	75

☐ PV Validation Check ☐ Noisy PV

Parameters
 Kc: 1.1
 N/A: 0
 N/A: 0
 N/A: 0
 Error DB: 0
 QV Limit: 100

Internal Connections
 Process Variable: Setpoint: Output Tracking:

Constraints

	Lower	Upper
PV	0	100
OP	0	100

Advanced OK Cancel

FIG. 26.9
 Controller configuration menu in CyboCon.

SISO MFA Configuration in CyboCon

Figure 26.9 shows the SISO MFA configuration screen in CyboCon software. A SISO MFA controller requires the configuration of the following parameters:

1. *Sample interval, T_s* : The interval between two samples or calculations in seconds. A high-speed MFA controller can run at 1 ms rate.
2. *Controller gain, K_c* : It is used to adjust the control performance. Set it higher for a more active control action, and set it lower for less overshoot.
3. *Time constant, T_c* : A rough estimate of the process time constant in seconds.
4. *Acting type*: Direct or reverse acting of the process. If the process input increases and then its output increases, it is direct acting, and vice versa. However, MFA controllers embedded in various platforms always use the vendor's definition. Sometimes, controller acting type is used, which is different than the process acting type.

According to the principles in the information theory, it is required that sample interval be smaller than or equal to one third of the Time Constant. That is,

$$T_s \leq \frac{1}{3} T_c, \quad (26.7)$$

where

T_s is the sample interval
 T_c is the time constant

As a rule of thumb, T_s can be set at 1 s for regular flow, pressure, and level loops, and 1 to 5 s for regular temperature loops. When dealing with high-speed control systems, T_s should be set at least 10 to 20 times smaller than the process time constant.

The software has the following additional features of MFA:

1. MFA does not require process identification and is not a dynamic modeling-based controller that requires

model training time. Therefore, once the configuration is done, MFA can be launched at any time and it will control the process immediately.

2. MFA can be switched between automatic and manual mode at any time.
3. The setpoint of the MFA control system can be changed at any time with any amplitude as long as the setpoint stays inside its limits and the process works within its operating range.
4. MFA does not have any potential signal saturation or wind up issues unlike the PIDs.
5. The standard control loop protection and enhancement features are implemented in CyboCon including setpoint limits, PV limits, control output limits, PV alarms limits, output velocity limit, error deadband, and PV noise filters, etc.

Nonlinear MFA Controller

In modern control theory, nonlinear control is one of the biggest challenges due to its complexity and countless types of nonlinear processes. Although linear control system theory has been well developed, the nonlinear control problems present the most difficulties for today's control scientists and engineers.

Nonlinear processes are difficult to control because the process input–output relationship can have so many behavioral variations. Traditionally, a nonlinear process has to be linearized before an automatic controller can be effectively applied. Typically, the linearization is achieved by adding a reverse nonlinear function to compensate for the nonlinear behavior so that the overall process input–output relationship

becomes somewhat linear. It is a tedious process to match the nonlinear curve and process uncertainties can easily hinder the effort.

For example, a pressure or flow loop is a typical nonlinear process that can cause the actuator to lose its authority in different operating conditions. Inevitable wear and tear on a control valve will make a linear valve nonlinear. The dissolved oxygen in a biotech micro-reactor to cultivate cells is another good example of a nonlinear process. The cells multiply exponentially as they grow and consume more and more oxygen. If traditional nonlinear characterization is applied, extra effort has to be made since the number of biotech experiments is large and the types of cells can vary significantly.

Nonlinear MFA is a general-purpose controller that provides a more uniform and effective solution to nonlinear control problems. It can be easily configured and launched to control various types of nonlinear processes.

Nonlinear MFA Configuration in CyboCon

The Nonlinear MFA controller has one extra parameter to configure when compared to the parameters used in the SISO MFA controller that includes sample interval, time constant, controller gain, and acting type. It has a special parameter, the process linearity factor, as shown in Figure 26.10. The graph illustrates the severity of the nonlinear behavior between the process input and process output.

The process linearity factor is a number between 0 and 10. A 0 represents a linear process and a 10 represents an extremely nonlinear process. Notice that the graph shows a nonlinear curve marked with 10 on both upper and lower positions, which implies that the nonlinear MFA controller

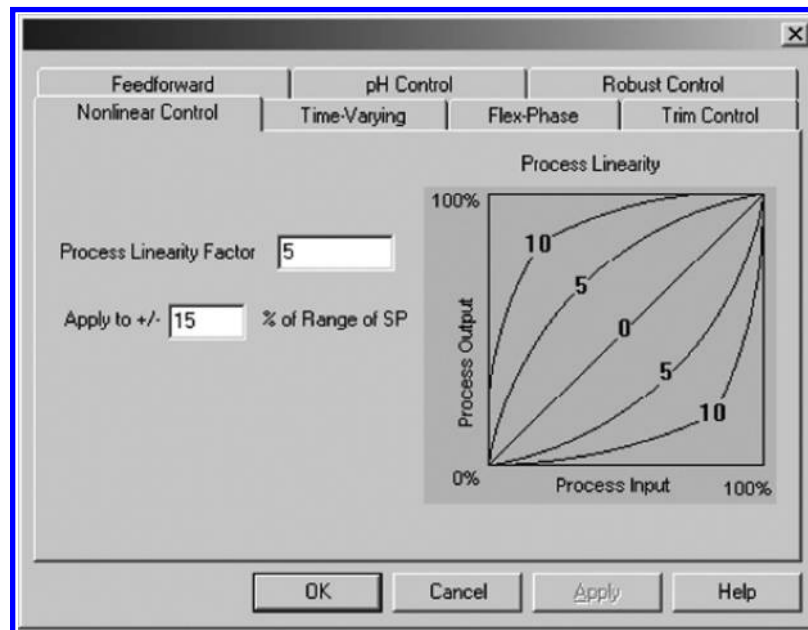


FIG. 26.10
Nonlinear MFA controller configuration menu.

does not care what the nonlinear characteristics are for this process. For instance, a valve in the control loop can be either “fast open” or “fast close” as represented by these two convex and concave curves.

When using the Nonlinear MFA controller, the process nonlinear curve can be concave, convex, S-shape, or arbitrary. Setting the controller to extremely nonlinear (9 or 10), quite nonlinear (5 or 6), or somewhat nonlinear (1 or 2) is sufficient. The MFA controller is smart enough to deal with the nonlinearity.

MFA pH Controller

Wastewater effluent generated in most process plants must be neutralized prior to discharge or reuse. Therefore, pH control is needed in just about every process plant, yet a large percentage of pH loops are not well controlled. Results are material waste, equipment corrosion, inferior product quality, and environmental pollution. Facing serious climate changes, energy crisis, and global competition, industries are under ever increasing pressure to improve plant efficiency and meet environmental regulations. Effective pH control is highly desirable.

A pH process can be complex and highly nonlinear. The pH is a measure of the acidity or basicity of a solution. It approximates the negative logarithm of the molar concentration of dissolved hydronium ions. A low pH indicates a high concentration of hydronium ions. From a process control point of view, a pH process is extremely nonlinear by its nature. Away from neutrality, the process gain is relatively small. Near neutrality where $\text{pH}=7$, the process gain can be a few thousand times higher. When a pH process is combined with large and varying time delays as well as large inflow rate and pH changes, the difficulty of this pH control loop quadruples. We not only must deal with the large gain changes but also the varying time delays. Dealing with a large gain change requires precise control action, and dealing with a varying time delay requires the controller to be predictive to “foresee” what is going to happen to avoid overreacting.

Often the PID controllers are not effective when controlling tough pH processes due to their limited capabilities. A “gain-scheduling” method might be used to deal with large pH gain changes. However, if the process also has large and varying time delays and variations in pH flow rate and inflow pH value, the “gain-scheduling” method will not work. For these reasons, most tough pH loops today are controlled by on–off control logics or simply left in manual control resulting in lower efficiency, large chemical consumption and waste, faster equipment corrosion and repair needs, and environmental consequences. On the other hand, model-based advanced control methods have been attempted to control tough pH processes. However, building and maintaining process models is difficult and often costly. Thus, large deployment of MBC for industrial wastewater treatment is not feasible.

The MFA pH controller and Anti-delay MFA pH controller can effectively control a wide range of pH processes within the full pH range. They are useful for wastewater

neutralization and can also be applied to control chemical concentration, which is a critical quality variable in the chemical processing industry.

MFA pH Controller Configuration in CyboCon

When an MFA pH controller is added in CyboCon, a set of default values is automatically shown with Break A=11, Break B=3, $K_{c1}=1$, $K_{c2}=0.001$, which assumes a strong-acid–strong-base pH process. From the configuration menu as shown in Figure 26.11, one can easily modify these parameters. Due to the adaptive capability, the titration curve does not have to be accurate and, in fact, its shape can vary in real applications. In addition, the flow rate and the pH value of the inflows may vary. The MFA pH controller can deal with these disturbances. If the flow rate changes significantly and it can be measured, a Feedforward MFA pH controller can be used to improve the performance.

Time-Varying MFA Controller

The Time-varying MFA controller was developed to control processes with large time constant and/or time-delay variations. Since adding heat to a process is much faster than taking it away, a temperature loop usually has a shorter time constant when it heats up and a much longer time constant when it cools down. This is a classical time-varying process. As another example, a line speed or flow rate change can cause the process delay time to vary significantly. In this regard, most industrial processes are time-varying to some degree.

Figure 26.12 shows the configuration menu for the Time-varying MFA controller in CyboCon. An estimated minimum and maximum process time constant plus delay time in seconds are entered. The controller is able to deal with the large time constant and/or delay time changes without having to retune any parameters.

Anti-Delay MFA pH Controller

An Anti-delay MFA pH controller is generated when combining the time-varying and pH control functions. It can control a pH process with large and varying time delays. See Figure 26.12 for the configuration menu of an anti-delay MFA pH controller.

When a pH process has large varying time delays as well as large inflow rate changes, the difficulty for this control loop quadruples. The extremely large gain changes with varying time delays worsen the situation, causing the process to become almost “uncontrollable.” Traditionally, a “bang–bang” type of control or batch-based pH neutralization would be the only solution.

The Anti-delay MFA pH controller has the combined capability of being predictive, adaptive, and robust. It is adaptive to compensate for the large gain changes, predictive to deal with large time delays, and robust enough to handle inflow changes, titration curve moves, and other uncertainties.

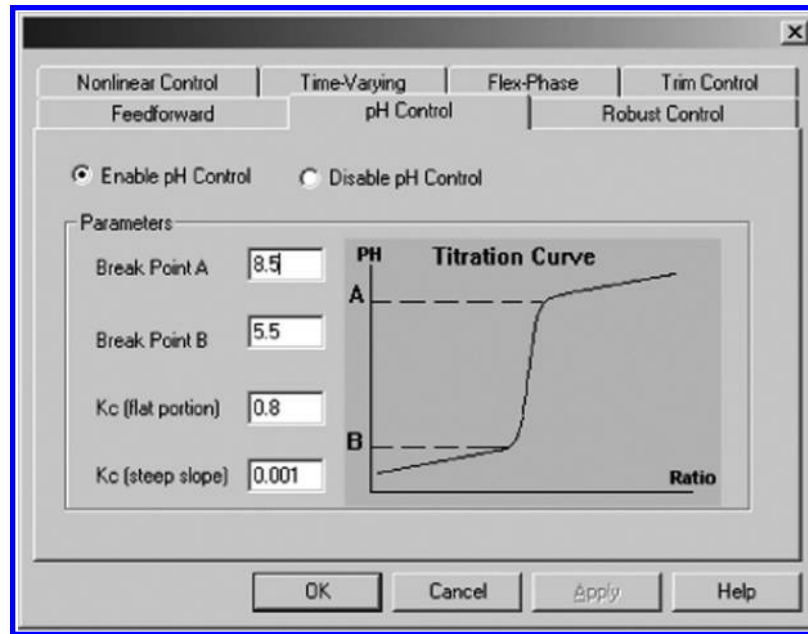


FIG. 26.11
MFA pH controller configuration menu.

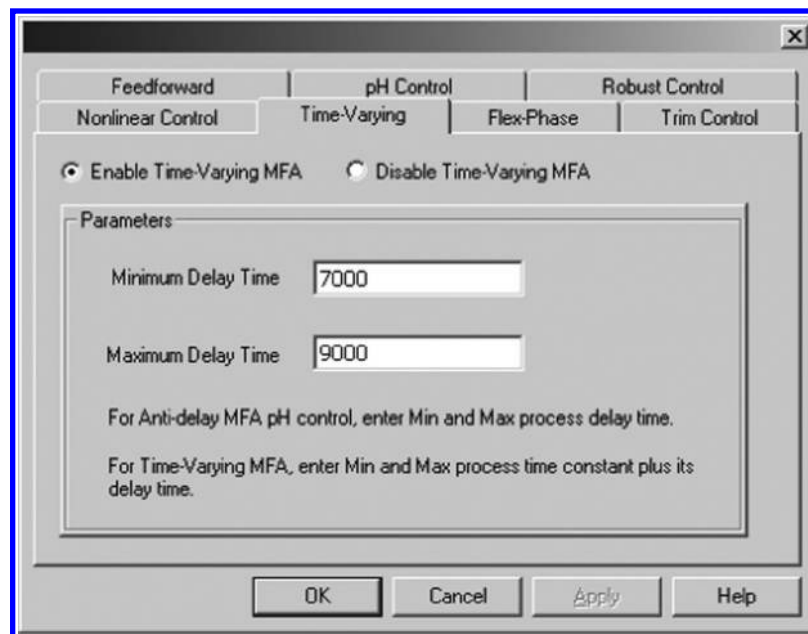


FIG. 26.12
Time-varying MFA and anti-delay MFA pH controller configuration menu.

MFA XRT Controller and Configuration

The MFA XRT controller is specially designed to control the exothermal reactor temperature, which is a non-self-regulating process that may also have large time delays. Typically, a non-self-regulating process such as a level loop can be controlled by using a P-controller. However, when the process also includes a large time delay, it is very difficult to control since (i) a non-self-regulating process requires a rapid control

action in order to search for a new balance point, and yet (ii) a process with a large time delay requires a “patient” control action while waiting for the PV to respond to its control action. These two requirements are generally in conflict.

The MFA XRT controller overcomes these difficulties by providing a “smart” control signal. Its performance is demonstrated and compared with a PID controller in the real-time simulation system that is included in the CyboCon Professional Edition software.

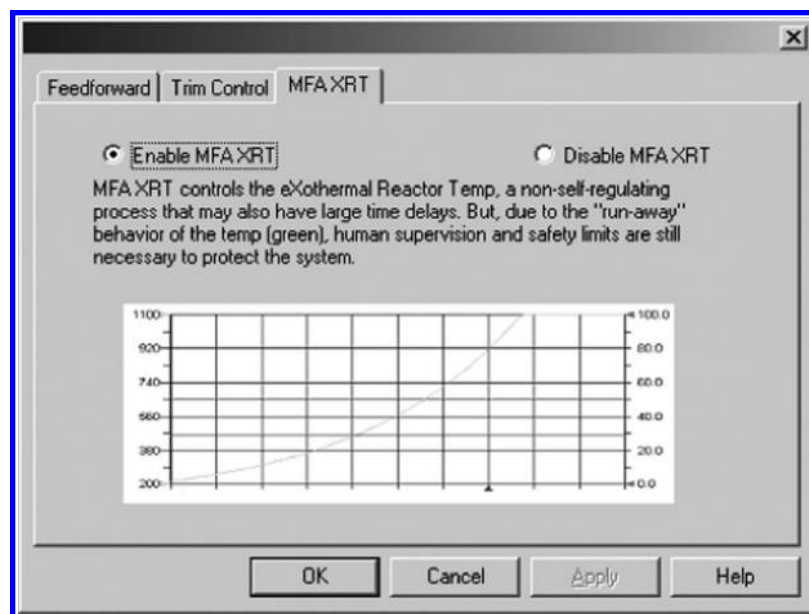


FIG. 26.13
MFA XRT controller configuration menu.

As shown in Figure 26.13, an MFA XRT controller can be configured in CyboCon. The user will first need to configure an Anti-delay MFA controller. Since the reactor temperature is a non-self-regulating process, there is no good measure for the conventional time constant. In this case, the T_c parameter is related to the reactor temperature ramping speed. The smaller the T_c , the faster the OP will move to deal with faster reaction speed.

MFA CONTROL TOOLSET FOR LabVIEW SOFTWARE

The MFA Control Toolset for LabVIEW software includes embedded MFA controllers for the LabVIEW® platform developed by National Instruments (NI). LabVIEW is the most widely used software for test, measurement, and control. From simple data acquisition to advanced embedded software development, LabVIEW is both user and developer friendly. The MFA controllers embedded in the LabVIEW real-time development environment can run in a PC, or be downloaded into NI's FieldPoint, cRIO, or PXI instruments providing high-speed control.

After the MFA Control Toolset for LabVIEW software is installed in a LabVIEW PC, the MFA icon will show on the LabVIEW Addons menu as illustrated in Figure 26.14.

After clicking the MFA VI icon, the following MFA controller VI screen will appear as shown in Figure 26.15. Each of the 20 MFA VI icons represents a controller. For instance, MFA-NL is the Nonlinear MFA controller VI.

For the standard edition of the software, 6 MFA VIs are included. For the Professional edition, more than 20 MFA VIs are included. This number is increasing as new types of



FIG. 26.14
LabVIEW addons screen.

controllers are developed. Table 26.3 lists different editions of MFA Control Toolset for LabVIEW software.

To explain, the MFA controllers are implemented in the LabVIEW environment, four different MFA controllers will be discussed as follows.

Feedforward MFA Controller and Configuration in LabVIEW

Feedforward is a popular control scheme to take advantage of disturbance signals. If a process has a significant yet measurable disturbance, a feedforward controller can reduce the

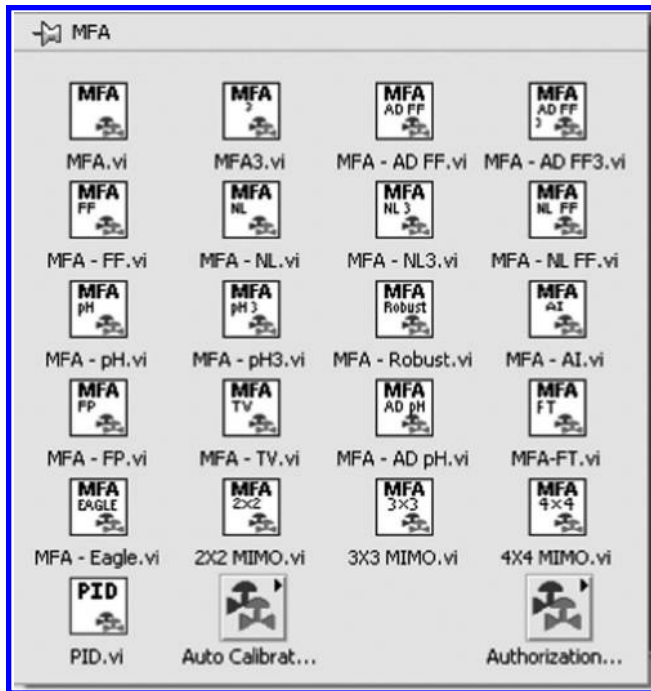


FIG. 26.15
MFA controller VIs in LabVIEW.

TABLE 26.3

MFA Control Toolset for LabVIEW Software Editions

Name	MFA VIs	Key
Standard Edition–Developer’s Pack	6	Hardkey
Standard Edition–Runtime License	6	Softkey
Professional Edition–Developer’s Pack	20	Hardkey
Professional Edition–Runtime License	20	Softkey

disturbance effect before the feedback controller takes corrective action. A good feedforward controller can economically improve the control system performance.

Feedforward compensation can be as simple as a ratio between two signals, or involve energy or material balance calculations that can be very complex. The Feedforward MFA is a general-purpose feedforward controller. Since the design philosophy for Feedforward MFA is not attempting a perfect cancellation of the disturbances, it is easy to configure and use. The adaptive and robust nature of the MFA controller makes this feedback and feedforward MFA control scheme very effective. Figure 26.16 shows a feedback–feedforward MFA control system, where G_{p1} is the main process and G_{p2} is the disturbance process.

The Feedforward MFA has been designed with two configurable parameters: (i) the feedforward gain and (ii) feedforward time constant. The MFA feedforward gain can be estimated by using the following formula:

$$K_{fc} = -\frac{K_{p2}}{K_{p1}}, \quad (26.8)$$

where K_{p1} and K_{p2} are the estimated static gain for processes G_{p1} and G_{p2} , respectively. In order to assure that the feedforward action rejects the disturbance, the rules for selecting the sign are (i) if processes G_{p1} and G_{p2} have the same sign, the gain should be negative and (ii) if processes G_{p1} and G_{p2} have different signs, the gain should be positive. The feedforward time constant can be an estimate of the time constant of G_{p2} . This is related to how fast the disturbance will affect the process PV. When using the controller, MFA feedforward gain and T_c can be just a rough estimate, but the sign for the gain has to be correct.

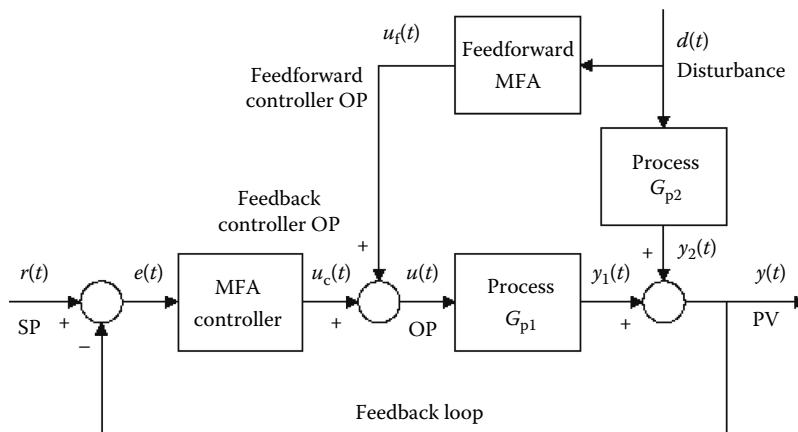


FIG. 26.16
Feedback and feedforward MFA control system.

Anti-Delay MFA Controller in LabVIEW

Many processes have large time delays due to the delay in the transformation of heat, materials, and signals. In this case, no matter what control action is taken, its effect cannot be measurable for a period of time. This is equivalent to disabling the feedback that is essential to automatic control. That is why large time delay is often considered the automatic controller's "killer."

When a PID is used to control a process with significant time delays, its output will keep growing due to its integral function during the delay time. It can cause a large overshoot or even make the system unstable. In practice, the PID has to be significantly detuned in order to stay in automatic but will sacrifice control performance. In general, a PID controller works for the process if its delay time/time constant (τ/T) ratio is smaller than 1, unless it is detuned. When the controller is detuned, sluggish performance will occur. A Smith Predictor could be useful to handle large time delays, but it requires a precise process model that can be difficult to obtain and maintain.

Figure 26.17 shows the block diagram for an Anti-delay MFA control system comprising an Anti-delay MFA controller and a process with large time delays. A special delay predictor is designed to produce a predicted PV signal $y_c(t)$ to replace the process variable $y(t)$ as the feedback signal. The idea here is to produce an $e(t)$ signal for the controller and let it "feel" its control action without much delay so that it will keep producing proper control signals. In other words, this artificial dynamic signal $y_c(t)$ is able to keep the feedback loop working even when there is a large time delay. Since MFA adapts, the delay predictor can be designed in a simple form [1,2].

Compared to a Smith Predictor, the Anti-delay MFA controller does not need a precise process model. The estimated delay time is the only additional information needed for the delay predictor. If the estimated delay time has a mismatch with the actual process delay time, the controller is adaptive and robust enough to handle the difference. Practically, the Anti-delay MFA controller can produce satisfactory control performance even if the estimated delay time is two to five

times larger or smaller than the actual delay time. In addition, there is no limitation on the size of the process τ/T ratio.

The Anti-delay MFA controller is especially useful in controlling process quality variables. This is because a quality variable is typically measured after the related product or material travels to a certain point, cools off, or forms its shape. This controller can be instrumental to the process industries in pursuing Six Sigma or zero defects quality control objectives.

In a semi-continuous production environment, things can get much more difficult. This is because the process line speed may change as many as 100 times or more, which will cause the delay time to change on a similar scale. That is why most semi-continuous processes cannot be easily controlled using feedback control systems.

In this case, the Anti-delay MFA controller can be advantageous compared with other control methods since it only requires an estimated process delay time, which can be calculated based on the measured line speed, the control performance will not sacrifice much even during large line speed changes. On the other hand, if the delay time of a process changes on a scale of more than five times and the delay time information cannot be provided to the controller, the time-varying MFA controller will be more suitable for this application.

Figure 26.18 illustrates an Anti-delay Feedforward MFA controller VI in the LabVIEW platform. The MFA VIs are designed with the same style and terminologies as used the NI's PID Controller VIs. This way, LabVIEW users can easily configure and launch MFA controllers in the LabVIEW platform without difficulty.

The VI picture and its signals are self-explanatory. The MFA parameter cluster includes the MFA gain K_c , the process time constant, the delay time, and the performance index. The Feedforward MFA parameter cluster includes the Feedforward gain and the time constant. The PV range cluster includes the upper and lower PV range.

Robust MFA Controller and Configuration in LabVIEW

In complex control applications, we often face some of the following challenges:

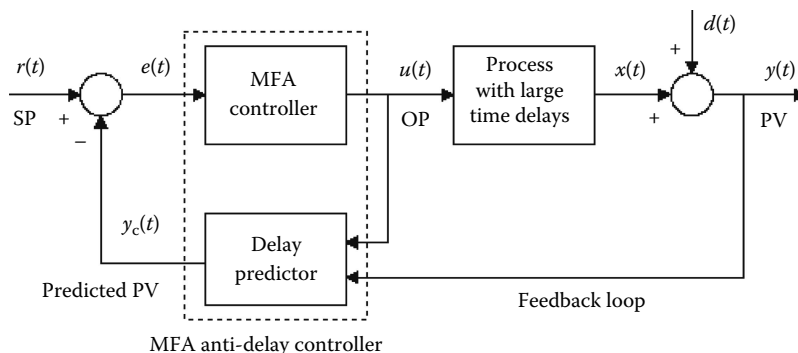
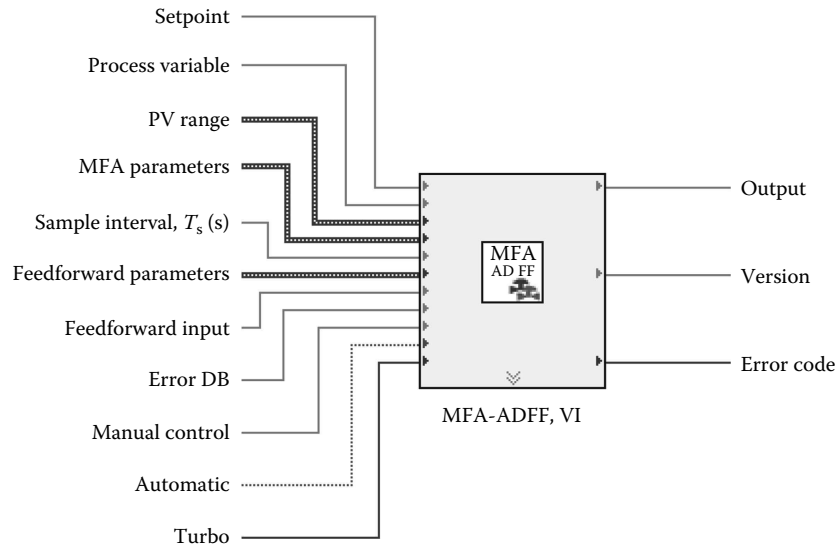


FIG. 26.17
Anti-delay control system.

**FIG. 26.18**

Anti-delay Feedforward MFA Controller VI for LabVIEW.

1. Large disturbances cannot be economically measured so that feedforward control cannot be applied easily.
2. There are significant process dynamic changes requiring the controller to generate prompt control actions in order to meet the control performance criteria.
3. Changes in process dynamic behavior or load do not provide triggering information to allow the control system to switch operating modes or reload the controller parameters.
4. A purposely detuned controller to minimize the variations in its manipulated variable may lose control when there is a large disturbance or dynamic behavior change.

For instance, a distillation column chain may include several cascading columns. The level of each column is controlled by manipulating its outflow. It is difficult to tune a PID controller to achieve good level control performance under all operating conditions. Overly tight level control will result in too much movement in the outflow, which can cause excessive disturbances to the downstream column. Therefore, a PID level controller is often detuned to allow the level to fluctuate; so the variations of the outflow are minimized. The detuned PID, however, cannot provide prompt control against large disturbances, which may result in the level being too high or too low during a plant upset. This can lead to major safety problems. In addition, oscillations in level loops can cause the process to swing for a long time causing lower production efficiency and yield.

Robust MFA controllers have been used for level control to allow smooth material and energy transfers between the distillation columns and protect the levels from overflowing or becoming too dry during abnormal conditions [22].

In general, the Robust MFA controller is able to deal with the complex situations described above. Without having

to redesign a controller, use feedforward compensation, or retune the controller parameters, the Robust MFA controller is able to keep the system in automatic control through normal and extreme operating conditions when there are significant disturbances or process dynamic changes.

Figure 26.19 shows the Robust MFA controller VI in LabVIEW. It includes a robust parameter cluster that has the following parameters:

1. *Upper and lower bound:* The bounds for PV being controlled. They provide “intelligent” upper and lower boundaries that are typically the marginal values the PV should not exceed. PV is unlike controller output (CO) where a hard limit or constraint can be set. PV is a process variable that can only be varied by manipulating the controller output. Thus, the upper and lower bounds for PV are very different from the CO constraints.
2. *Gain ratio:* The coefficient to increase or decrease the MFA control action based on where PV is. For instance, gain ratio=3 as its default setting. As PV gets closer to reaching its bounds, MFA will react like it has a gain that is three times higher than its setting. Notice that this is not a gain-scheduling approach, although it appears to be. Gain scheduling will not be able to resolve the complex problems described.

3 × 3 MIMO MFA Controller in LabVIEW

The Multivariable MFA control system was introduced in the early part of this chapter. We now present a 3-Input–3-Output (3×3) MFA controller VI in LabVIEW. As shown in Figure 26.20, this 3×3 MFA controller VI has three controller cluster inputs as controller 1, controller 2, and controller 3.

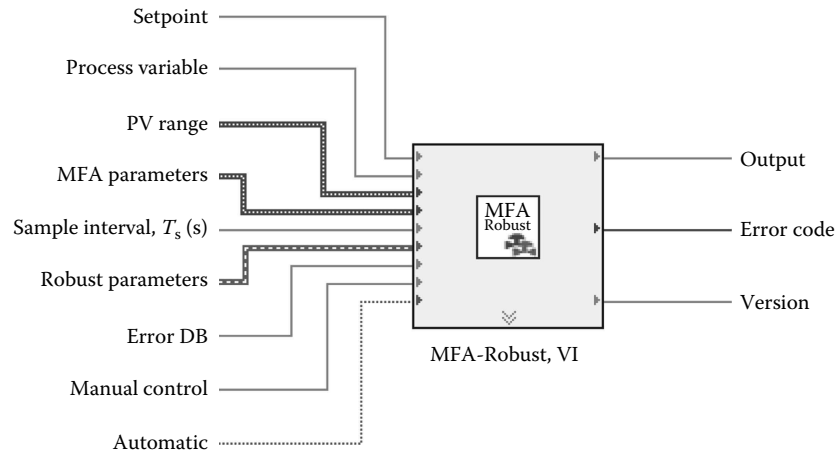


FIG. 26.19
Robust MFA controller VI for LabVIEW.

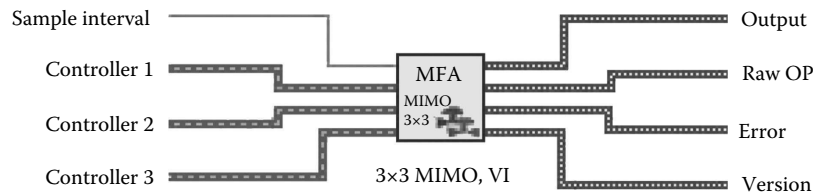


FIG. 26.20
A 3×3 MIMO MFA controller VI for LabVIEW.

Each controller cluster includes a number of variables and parameter clusters as illustrated in Figure 26.21. The user needs to make the proper connections for the variables and parameters.

A 3×3 MFA controller can be considered to have three main controllers C_{11} , C_{22} , and C_{33} . For each main controller, the parameters to configure are

1. *Sample interval, T_s* : The interval between two samples or calculations in seconds. A high-speed MFA controller can run at a 1 ms rate.
2. *Controller gain, K_c* : It is used to adjust the control performance. Set it higher for a more active control action, and set it lower for less overshoot.
3. *Time constant, T_c* : A rough estimate of the process time constant in seconds.
4. *Acting type*: Direct or reverse acting of the process. If the process input increases and then its output increases, it is direct acting, and vice versa. However, MFA controllers embedded in various platforms use the vendor's definition. Sometimes, controller acting type is used, which is different than the process acting type.
5. *Compensator gain, K_{c2} , K_{c3}* : It is used to deal with the interactions from the other loops.

MIMO MFA Controller Application Guide

Since a MIMO system is much more complex than a SISO system, precaution has to be taken when applying MIMO MFA controllers. When designing a multivariable control system, the first step is to decide which process variable is paired with a manipulated variable. As an example, a 2×2 MFA control system should be designed based on the following variable pairing rules:

1. Each process of the main loops has to be controllable, open-loop stable, and either reverse or direct acting.
2. A process with a large static gain should be included in the main loop as the main process (G_{11} , G_{22}) and a process with a small static gain should be treated as a subprocess (G_{21} , G_{12}).
3. A faster process should be paired as the main process and a slower process and processes with time delays should be treated as subprocesses.
4. If pairing rules 2 and 3 are in conflict, a trade-off is the only option.

As a general guide, an MFA control system needs to be designed based on the degree of interactions between the loops. Table 26.4 lists the MIMO MFA control system design strategy for a 2×2 process.

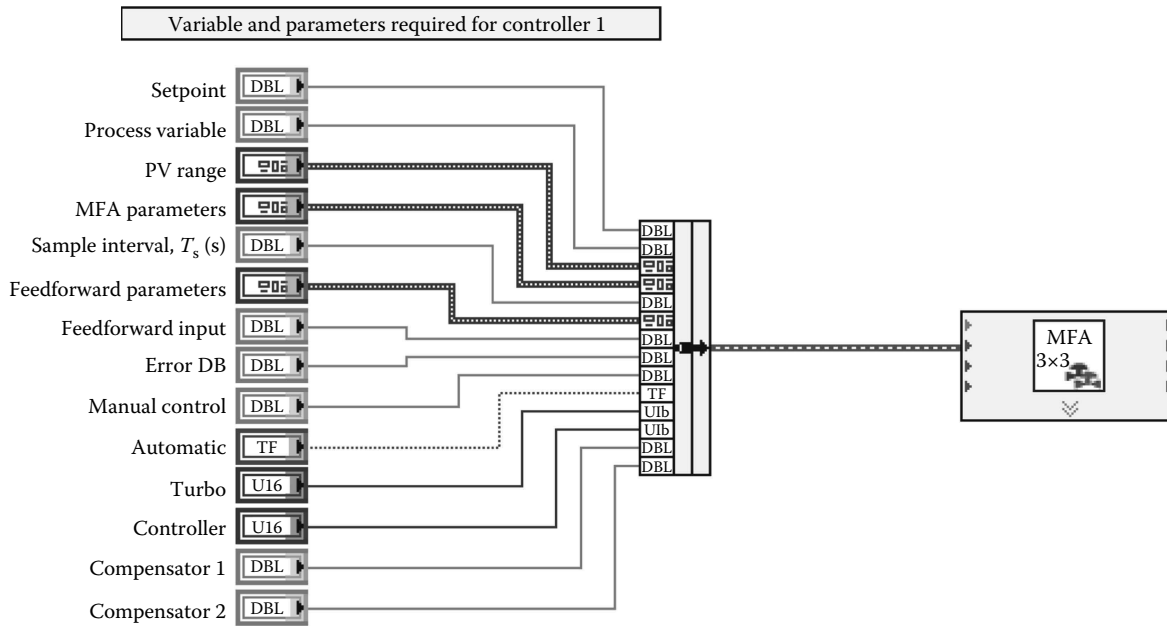


FIG. 26.21
Variables and parameters for controller 1 cluster in 3×3 MFA VI.

TABLE 26.4

MIMO MFA Control System Design Strategy

Interaction Measure	Control Strategy
Small to noninteraction	Use 2 SISO MFA controllers to achieve good control. MIMO MFA is not needed
Moderate interaction	Use a 2×2 MFA controller to achieve better overall control than SISO controllers
Severe interaction	Use a 2×2 MFA controller to achieve good control. May need to detune the less important loop

MFA CONTROL TOOLBOX FOR MATLAB® SOFTWARE

The MFA Control Toolbox for MATLAB® software includes a set of embedded MFA controller S-functions that work as control function blocks in the Simulink® environment. Anyone who is familiar with Simulink can easily configure and use the MFA control blocks to perform off-line simulations. It is a useful tool for research, development, teaching, and lab testing.

Developed by Mathworks, Inc., MATLAB and Simulink are the most popular simulation tools. MATLAB is a high-level language and interactive environment that enables users to perform computationally intensive tasks faster than with traditional programming languages. Simulink is a platform for multi-domain simulation and model-based design for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications.

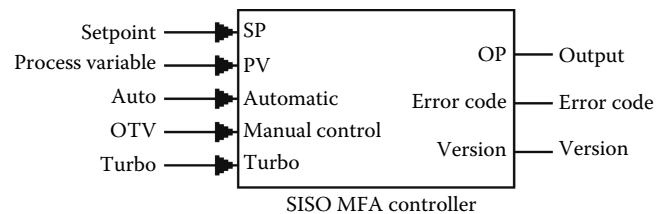


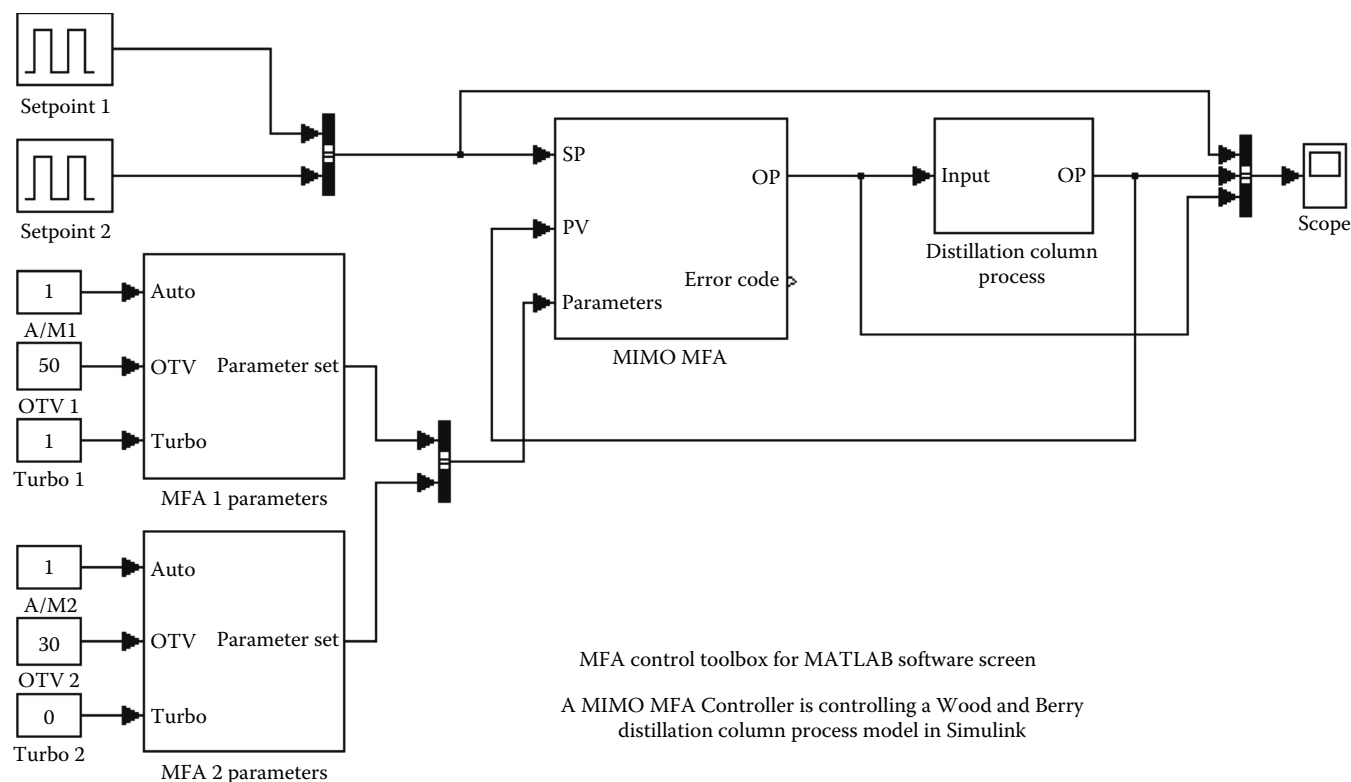
FIG. 26.22
SISO MFA controller S-function in MATLAB.

The MFA Control Toolbox for MATLAB software is designed for the science and engineering community. It enables users to simulate, test, and evaluate the MFA controllers on process models built in the MATLAB/Simulink environment. Using variety of MFA controllers in the MFA Control Toolbox, one can solve various control problems to prove the concept with computer simulations before launching the MFA control system using other real-time MFA control methods.

A SISO MFA controller S-function in MATLAB/Simulink is shown in Figure 26.22. The variables as inputs to the function are SP, PV, automatic switch, OTV, and turbo.

Figure 26.23 is a Simulink screen that shows a 2×2 MIMO MFA controller that is configured to control the well-known Wood and Berry distillation column model. The blocks show MFA 1 parameters and MFA 2 parameters. They are the MFA parameter configuration blocks for MFA 1 and MFA 2 of this 2×2 MFA controller.

There are two setpoint signals since this is a 2×2 control system. The two setpoints feed into the MFA S-function with only one signal line. This implies that there may be multiple signals inside each signal line. For example, the signal line

**FIG. 26.23**

A MIMO MFA control system in Simulink.

from the model output to the controller PV has both PV1 and PV2 signals.

MFA CONTROL APPLICATIONS

Since its introduction in the fall of 1997, MFA has been widely deployed in many industrial plants controlling critical process variables and quality variables including temperature, pressure, level, flow, density, concentration, pH, moisture, and product dimensions, etc. In the following, several MFA application case studies will be presented to show how MFA can solve some of the difficult control problems in industry [13–28].

MFA for Ethylene Quench Water pH Control

In an ethylene plant, hydrocarbon feedstock is cracked to produce ethylene. Py-gas is a by-product of the process and needs to be cooled by direct contact with the quench water in a water tower. The py-gas contaminates the quench water and can cause emulsion making the separation more difficult. It can also foul the dilution steam system and associated components. Therefore, effective pH control for the quench water is critical. However, these pH loops are nonlinear and have large and varying time delays. Most quench water pH loops are left in manual control, resulting in lower efficiency,

wasted chemical reagent, equipment corrosion, and higher maintenance costs.

PetroChina has deployed many MFA control systems including quench water pH control in multiple ethylene plants. Figure 26.24 illustrates an MFA control system for a typical quench water process. The control objective is to maintain the quench water pH at 7 ± 0.5 . Caustic water is added at the bottom of the tower to the circulating quench water, and at the bottom of the process water stripper and dilution steam drum [26].

Since the pH process has a varying delay time of 0.5 h and a time constant of 2 h, it is extremely difficult to control either manually or by using other control methods. Under manual control, quench water pH varies between 5.77 and 7.47 (Variation Range=1.7) as illustrated in Figure 26.25.

To handle the large and varying time delays, an Anti-delay MFA controller was selected, shown in Figure 26.12. In the configuration, the minimum delay time was estimated at 7000 s (2 h) and the maximum delay time was estimated at 9000 s (2.5 h). Since it is the estimated range of the delay time and time constant, such information can be obtained by studying the process trends.

Under MFA control, the variation range of quench water pH is sharply reduced to 6.9–7.18 (variation range=0.28). The control trend in Figure 26.26 records about 12 h of data and is a good demonstration of the MFA control performance. The pH setpoint is at 7.0; and the MFA controller

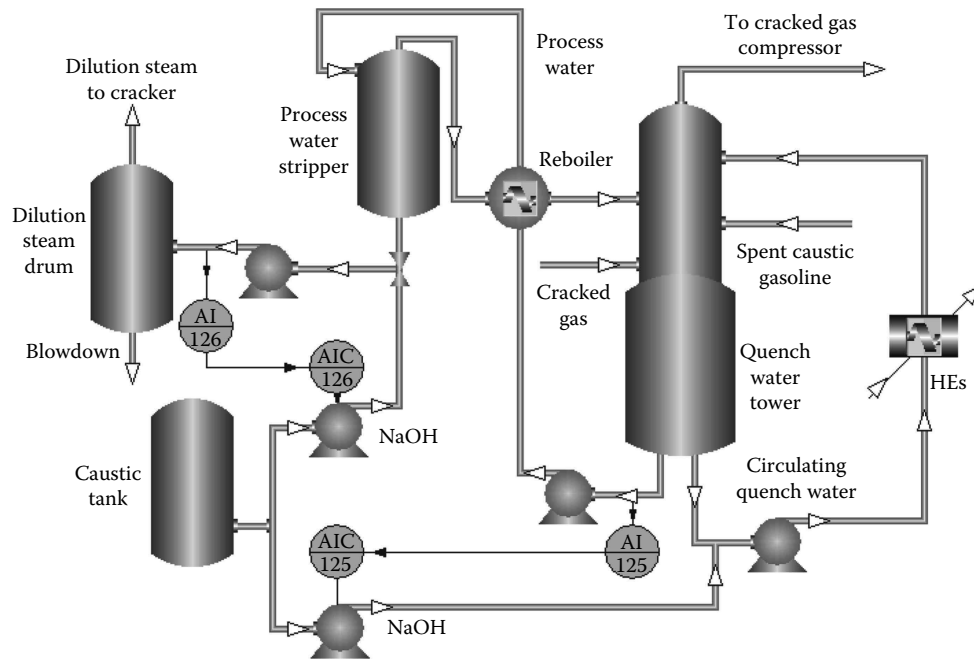


FIG. 26.24
MFA control system for ethylene quench water pH process.

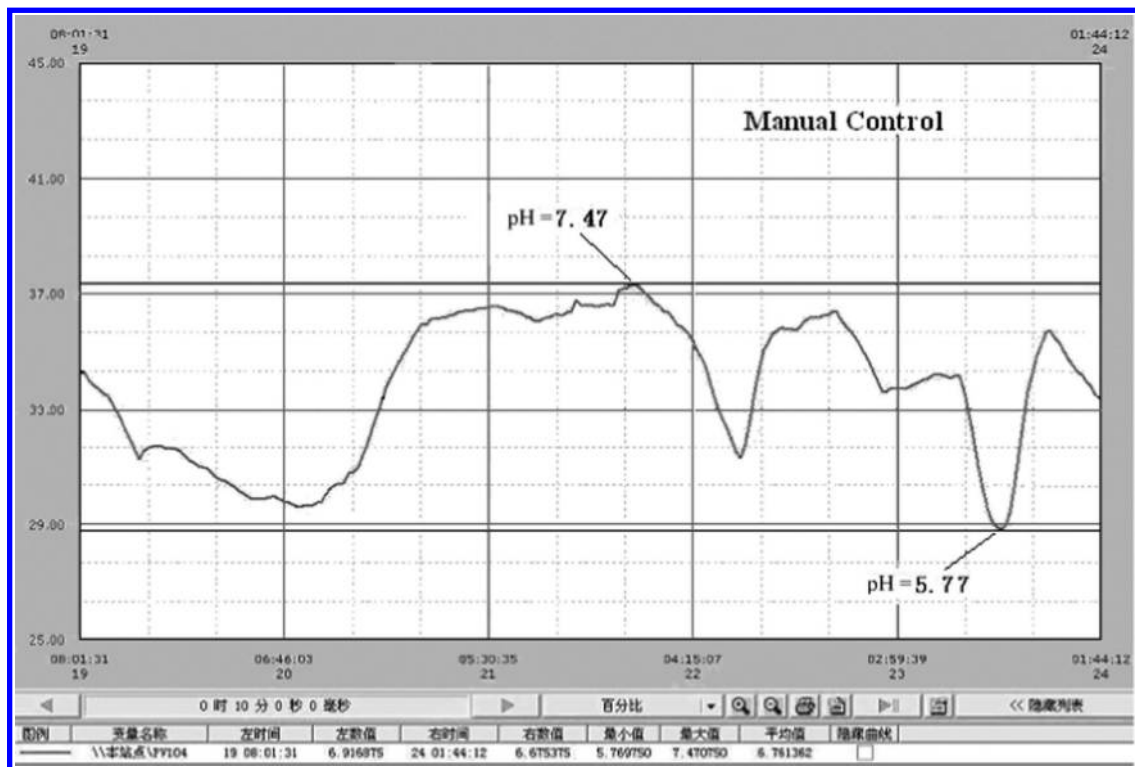


FIG. 26.25
Manual control trend of quench water pH process.

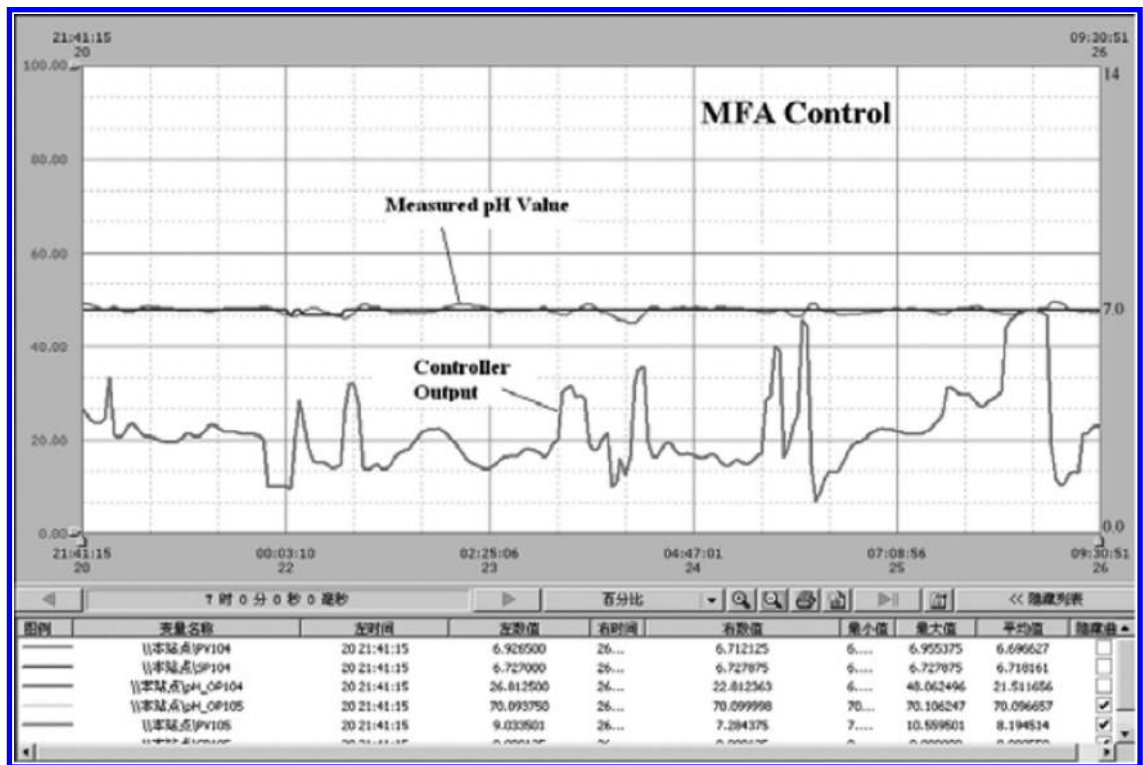


FIG. 26.26
MFA control trend of quench water pH process.

output changes 7%–50% in the operation range 0%–100%. This means that MFA makes significant adjustments to the caustic flow in order to keep the pH value under control with only 0.28 variations. Noting that there is about a 2–2.5 h time constant and delay time in the process, it is not feasible for a human operator to have the time and patience to manually control this process and achieve similar control performance.

MFA Control for Gas-Mixing Systems

In an iron and steel complex, blast furnaces, basic oxygen furnaces (BOF), and coking ovens all produce gases as by-products. Many plants discharge these gases into the atmosphere wasting valuable energy and causing air pollution. Gas plants are built to collect the wasted gases and mix them to produce fuel for metal casting and rolling mill furnaces. The quality of the mixed gas is measured by its heating value. Gases with inconsistent heating value can cause major control, quality, and production problems due to over or under heating.

Even during normal production, gas supply and demand can change randomly. Major operating units like blast furnaces and reheating furnaces may go on and off-line periodically causing large disturbances in gas flow, pressure, and heating values.

A turnkey MFA control solution is offered by CyboSoft for this application. A soft sensor is able to estimate the gas heating value online. Nonlinear MFA controllers are used to control the gas flow and differential pressure loops. Robust

MFA controllers are also used to handle the constraints and protect the system from running in vicious cycles. An anti-delay MFA controller is used to control the gas heating value by cascading with the gas flow and gas pressure controllers.

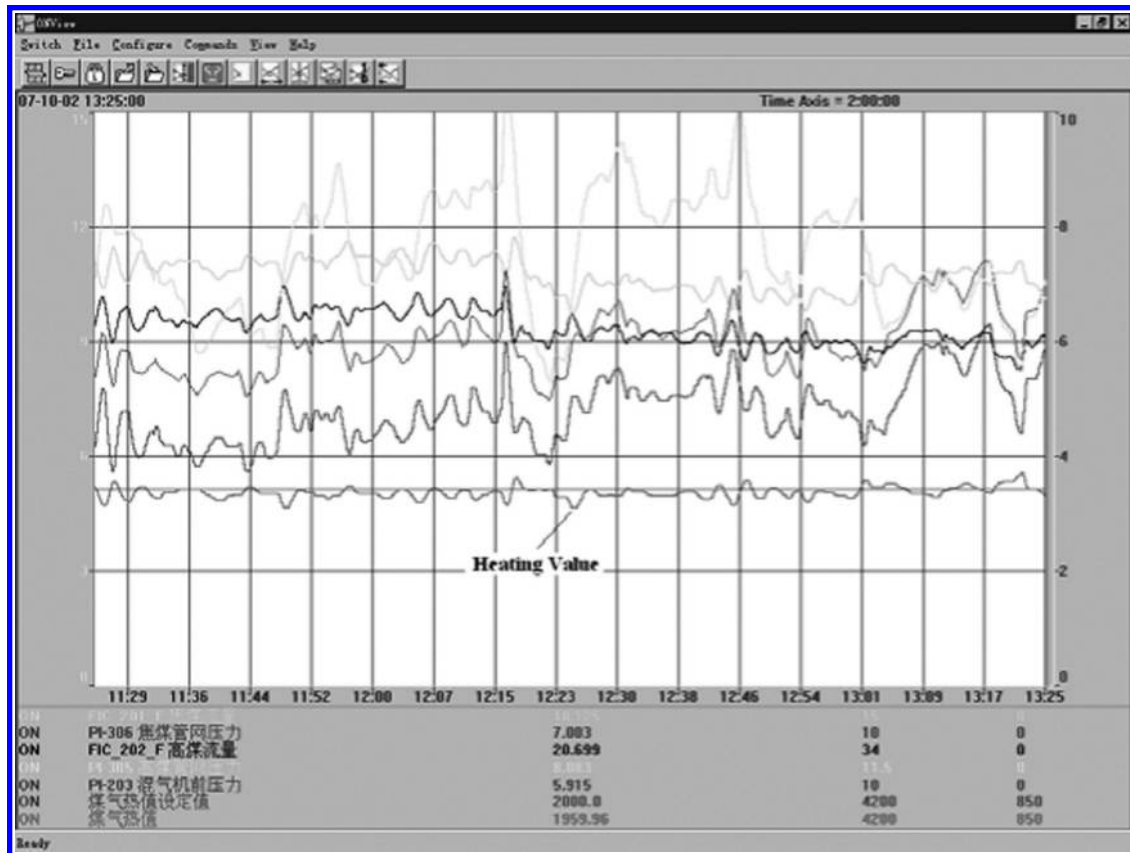
Since 2002, MFA control systems have been launched to control a number of gas-mixing facilities in iron and steel plants. As illustrated in Figure 26.27, the trend chart shows good control of the heating value when there are major gas disturbances from blast furnaces and coking ovens. This application resulted in

- Gas heating value controlled within $\pm 100 \text{ kcal/Nm}^3$ specification
- Improved product quality, plant safety, and production efficiency
- More flexible production [18]

MFA for Building Automation

Since 2005, Siemens has been delivering embedded MFA controllers as part of its APOGEE® building automation system (BAS). It is estimated that Siemens launches about 100,000 new MFA control loops annually.

Building control has its own set of problems, including (i) very broad applications with many different types of buildings and HVAC system configurations, (ii) many systems are designed with over-sized valves and dampers, and actuators may be in bad shape making the process very nonlinear, and

**FIG. 26.27**

MFA control trend for a gas-mixing system.

(iii) variations in season, load, and climate make controller tuning difficult and costly.

MFA building control loops perform well consistently resulting in better comfort, energy savings, and lower maintenance costs. Jeff Wills, Sr. Product Manager, Siemens Industry Inc., Building Technologies Division, said,

“Thanks to MFA technology, which is a leading-edge and well-established industrial control algorithm, APOGEE® system users can achieve increased valve and actuator life expectancy. The reduction in cycling-induced wear and tear on valves and actuators increases their lifespan and reduces repair, replacement, and maintenance costs for end devices. This control solution also eliminates the need for seasonal retuning because it continuously and automatically adjusts to system changes [28,32].”

MFA for Drilling Equipment Control

Since 2006, Canrig Drilling, a leading drilling equipment company, has been delivering embedded MFA controllers in its DrillSmart® drilling control systems to achieve safer and more efficient oil and gas well drilling. In their operations, MFA's adaptive and robust controllers are used particularly making lateral drilling much easier [33].

Oil or gas well drilling is often done manually. Automatic drilling equipment is developed to improve the drilling

safety and efficiency by automatically controlling the “rate of penetration” and “weight on bit.” An auto-driller can drill through the soft strata quickly and slow down immediately when encountering the hard strata. Since each rig can be different due to design, type, location, and operating conditions, a PID-based control system often requires retuning of its parameters requiring extensive technical support.

An MFA-based auto-driller eliminates the controller tuning and deals with major disturbances and uncertainties. From this case study, we can conclude that MFA is well suited for control applications where reliable high-speed intelligent control is required to deal with rapid process dynamic changes as well as large and random disturbances.

MFA METHODOLOGY: COMBINED INTELLIGENCE

A problem usually has multiple possible solutions, and a process can usually be controlled using different controllers based on different control methods. Almost every control method has its merits and weaknesses. The important thing is to use the right controller to fit a particular application at a minimum cost.

In natural science, the combination of physics, mathematics, and philosophy plays an integral part in developing a theory that is practically useful. Physics is the foundation for

the study of the physical process or environment, mathematics provides the tools to precisely describe the physical process or phenomenon, and equally important is the philosophy that provides directions.

The development of MFA control technology starts from a new controller idea that can easily and effectively solve various industrial control problems. The technique evolves from combined intelligence methodology. MFA control does not follow the traditional path of model-based adaptive control, but the philosophy behind the combined intelligence leads to very effective applications.

Combined Intelligence Methodology

The combined intelligence methodology developed by the author of this chapter consists of the following problem-solving philosophy:

1. Always seek a simple solution for a complex problem
2. Use all the available information
3. Do not be dependent on the accuracy of information
4. Apply a technique that fits the application

These four key points are described in the following:

Seek a Simple Solution: A simple solution is almost always the best solution. A complex solution might achieve a slightly better result, but the cost can be very high. Most users want to have a tool or system that is easy to use, launch, and maintain with the best price–performance ratio. A simple solution usually fits this need well.

In the case of MFA philosophy, PID control is simple since it is a general-purpose controller and its algorithm is easy to understand. However, PID is almost too simple to control complex systems. In this regard, PID cannot be considered an effective solution to the more difficult control problems. On the other hand, model-based advanced control methods have proven themselves too complex to launch and maintain since they depend on either a first principle or an identification-based process model. A dream controller has to be powerful enough to control various complex processes yet simple enough to use, launch, and maintain. MFA is a solution that fits these requirements.

Use All the Available Information: It is a cliché, but we are living in the information era. Information has value. A small piece of information can make all the differences. When solving a problem, do not waste the valuable information available. For instance, a process delay time can easily be seen from the process trend chart. A regular PID controller ignores this important piece of information.

In the case of MFA philosophy, as the name MFA suggests, it is a control method that does not depend on either first principle or identification-based process models. However, all the available process information is used. For this reason, it can be considered as an information-based controller.

For instance, process time constant defines how fast a dynamic system responds to its input. A slow process might have a 10h time constant and a fast process might have a 10ms time constant. It would be unwise not to use this information for the controller. In addition, it is relatively easy to estimate the time constant by reading a trend chart. Other important yet easily obtained information about a process includes its acting type (either direct or reverse), static gain, and delay time if any. An MFA controller is designed to use the process parameters that can easily be estimated.

Do Not Be Dependent on the Accuracy of Information: All information received may not be accurate. We might not even know whether the information is accurate or not. If we knew, we would simply have the option to use or not use the information. For this reason, the solution has to be agile or adaptive enough to deal with the inaccuracy of the information and the uncertainties.

In the case of MFA philosophy, a process can be classified as a white, gray, or black box. If its input–output relationship is clear, the process is a white box. We can easily use existing well-established control methods and tools to design a controller for this process.

If there is doubt on the accuracy of the process input–output relationships, or if the process has potential disturbances, dynamic changes, and uncertainties, the process is a gray box. In this case, MFA's adaptive capability is able to handle such changes and uncertainties. PID or MBC methods will have a much harder time or will incur higher costs addressing these uncertainties.

Apply a Technique That Fits the Application: Arguments often arise between people who believe in very different problem-solving methods. For instance, model-based and rule-based methods are two very distinctive approaches in control theory. Since almost all methods have their merits and shortcomings, one can use the technique that fits the application best [12].

In the case of MFA philosophy, it is neither model-based nor rule-based. Basically, it is an information-based control method. A series of MFA controllers, many of which are described here, are developed to address different control problems. Users can select the appropriate MFA controller, configure its parameters, and launch the controller. After a correct set up, manual tuning and maintenance are not required [12].

In conclusion, MFA control takes a “one-algorithm-solves-one-problem” approach and has proven to be effective, and can be deployed in many applications.

MFA FUTURE OUTLOOK

MFA control system was first installed in a running industrial plant in late 1997, and since then it has been deployed in almost every sector of the industry. As a relatively new technology, MFA had to go through development, validation, and

marketing stages to gain large-scale acceptance in many control applications. Although the future of MFA looks promising, two critical issues are yet to be addressed:

1. Most industrial plants are controlled by using PLCs and DCS. In order for industrial users to easily and cost-effectively adopt MFA to control their equipment, processes, and plants, it is preferable to run embedded MFA controllers inside their new and existing PLC and DCS systems.
Persistent efforts have been made to embed MFA controllers inside popular control products such as the LabVIEW. At the time this chapter is being written, CyboSoft is developing a new product, MFA Control Software for Open-PLCs. It includes embedded MFA controllers for PLC and DCS products that support the IEC 61131-3 standard. This way, users can select and configure the MFA control function blocks in their familiar product environment using IEC 61131-3 PLC programming tools.
2. The largest obstacle in the proliferation of the MFA control technology is the “PID is good enough” syndrome. In the automation industry, because of wider acceptance of PID control, many users are afraid of making any changes, even if the methods used might be outdated and wasteful [28].

Nevertheless, MFA is a proven control technology that has unique advantages over PID and MBC. In some applications, they should coexist and complement each other. MFA control solutions are fulfilling some of the urgent needs of industry to improve product quality and efficiency, achieve energy savings, and reduce emissions. MFA also has potential in renewable energy, biotech, life science, and health care industries. It is our mission to continue innovation and deliver the technology, products, and solutions that benefit the industry and society.

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